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Noise Control of Diesel-Powered Underground Mining Machines, 1979

Compiled by J. H. Daniel, J. A. Burks,
R. C. Bartholomae, R. Madden, and E. E. Ungar

UNITED STATES DEPARTMENT OF THE INTERIOR

United States. Bureau of Mines.

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James G. Watt, Secretary

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NOISE CONTROL OF DIESEL-POWERED UNDERGROUND MINING MACHINES, 1979

Compiled by

J. H. Daniel,[1] J. A. Burks,[2] R. C. Bartholomae,[3] R. Madden,[4] and E. E. Ungar[4]

ABSTRACT

This Bureau of Mines report presents results of a survey of underground mining equipment and of two demonstration programs showing the feasibility of quieting a load-haul-dump (LHD) machine and a personnel vehicle. Typical noise levels are presented for the major machine types used in underground mines, along with estimates of the noise overexposure of miners who operate or work near these machines. General principles of noise control are explained, and the application of these principles is illustrated in the description of modifications made to the LHD machine and the personnel vehicle. The noise control package installed on the personnel vehicle lowered its noise level by 14 dBA after 4 months of operation, and inspection of the LHD machine after 2½ years of operation with the modifications showed its noise level 7 dBA lower than that of the unmodified machine. Noise dosimeter measurements indicated that both machines were in compiliance with Federal noise regulations for a typical shift.

INTRODUCTION

A great many machines currently used in underground metal and nonmetal mines are powered by diesel engines, which often produce relatively high levels of noise. Because Federal regulations[5] limit the permissible noise exposure of personnel, the Bureau of Mines has sponsored studies to assess the noise exposure of workers from diesel-powered equipment and to demonstrate that engineering noise control of these machines is feasible.

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[5]Federal Mine Safety and Health Act of 1977 (Public Law 95-164).

This Information Circular summarizes the results of a survey of mining equipment and two demonstration programs that demonstrate the feasibility of quieting a load-haul-dump machine and a personnel vehicle. Details of each of these programs are available.[6]

FEDERAL NOISE REGULATIONS

Miners are not usually exposed to the same noise level continuously; most commonly they experience noise levels that change throughout the working day. Since higher noise levels constitute more of a hearing hazard than lower ones, the effects of these different levels must be accounted for. The "noise dose" is a standard measure that accomplishes this accounting and also relates a worker's total noise exposure to the permissible limit.

Federal regulations permit a worker to be exposed to a noise level of 90 dBA for 8 hours per day and prescribe a halving of the permissible exposure time for each 5-dBA increase in noise level, as shown in table 1.

A miner who is exposed for C hours per day to a noise level for which the permitted exposure duration is T hours is considered to be subjected to a noise dose of C/T because of this exposure. Thus, a noise dose that exceeds 1.0 represents an excessive exposure, whereas a noise dose of less than 1.0 corresponds to an exposure that is within the permissible limits.

[6] The following reports are available from the National Technical Information Service/(NTIS), Springfield, Va. (order by PB number) and for inspection (on open file) at the following facilities: Bureau of Mines--Denver, Colo., Twin Cities, Minn., Bruceton and Pittsburgh, Pa., and Spokane, Wash.; U.S. Dept. of Energy--Carbondale, Ill., and Morgantown, W. Va.; National Mine Health and Safety Academy, Beckley, W. Va.; and National Library of Natural Resources, U.S. Dept. of the Interior, Washington, D.C.

Huggins, G. G., R. Madden, and B. S. Murray. Noise Control of an Underground Load-Haul-Dump Machine. BuMines Open File Rept. 125-78, July 1977, 79 pp., contract H0262013; NTIS, PB 288 854/AS.

Huggins, G. G., and W. N. Patterson. Reducing the Operator Sound Level of a Mining Service Vehicle--A Demonstration Project. BuMines Open File Rept. 47-77, November 1975, 75 pp.; contract H0346046; NTIS PB 265 037/AS.

Patterson, W. N., G. G. Huggins, and A. G. Galaitsis. Noise of Diesel-Powered Underground Mining Equipment. Impact, Prediction, and Control. BuMines Open File Rept. 58-75, March 1975, 227 pp.; contract H0346046; NTIS, PB 243 896/AS.

TABLE 1. - Permissible noise exposures

Duration of exposure per day, hours	Noise level, dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25	115

NOTE.--Noise levels are measured with a sound level meter set to slow response. Exposure to continued levels above 115 dBA is not permitted. Values between those tabulated may be obtained from

$$T = \frac{8}{2^{(L-90)/5}},$$

where T denotes the daily exposure duration in hours and L the noise level in dBA.

If a miner is exposed to different noise levels throughout the day, one may evaluate the miner's total noise dose simply by adding up all of the C/T values corresponding to the various noise levels.[7] Commercially available instruments called noise dosimeters perform this dose evaluation automatically and continuously.

MACHINERY NOISE LEVELS AND WORKER EXPOSURE

Machine Types and Numbers in Use

Discussions in 1975 with the regional offices of the Mine Safety and Health Administration, with State mining inspectors, and with major underground mine operators revealed that 2,638 specific pieces of diesel-powered equipment were being used in underground metal and nonmetal mines. This survey did not cover all mines in the United States; however, extrapolation of the survey data leads to an estimate of about 4,000 for the total number of items in use. Table 2, which shows the distribution of the machines counted in the survey by type and engine power, indicates that more than 50% of these machines had less than 100 hp and that load-haul-dump machines, ore trucks, and service trucks were the most prevalent.

[7]For example, a person exposed to 90 dBA for 6 hours, to 100 dBA for 1 hour, and to 70 dBA for 1 hour per day receives a dose of (6/8) + (1/2) + 0 = 1.25, and thus is overexposed. Similarly, a person exposed to 97 dBA for 1/4 hour, 95 dBA for 2 hours, 90 dBA for 3 hours per day, and to noise levels less than 90 dBA for the remainder of the working day receives a dose of (0.25/3) + (2/4) + (3/8) + 0 = 0.958, and thus is not overexposed.

TABLE 2. - Numbers of machines found in use, by type and engine power

Types of equipment	Under 100 hp	100-200 hp	Over 200 hp	Total
Production machines:				
Ore trucks	227	66	172	465
Load-haul-dumps	147	190	49	386
Front-end loaders	44	97	45	186
Jumbo drills	112	33	4	149
Locomotives	67	11	0	78
Roof bolters and scalers	32	20	0	52
Shuttle cars	29	14	0	43
Explosive buggies	12	24	0	36
Skid-steer loaders	31	0	0	31
Ram haulers	1	8	5	14
Tractor-trailer units	0	6	8	14
Total	702	469	283	1,454
Support Equipment:				
Service trucks	187	16	2	205
Personnel carriers	199	2	0	201
Jeeps	132	0	0	132
Tractors	76	3	1	80
Transit mixers and placers	35	0	0	35
Motor graders	14	16	0	30
Cranes and shovels	6	17	1	24
Dozers	8	4	5	17
Air compressors	5	1	9	15
Welders and generators	10	1	1	12
Pickup trucks	6	3	0	9
Shotcrete machines	6	0	0	6
Pumps	2	0	0	2
Total	686	63	19	768
Unclassified	165	170	81	416
Total	1,553	702	383	2,638

Noise Doses and Exposure-Weighted Worker Population

Table 3 indicates the noise dose to which each type of machine typically subjects each operator and bystander. For each machine type, table 3 shows the typical engine power and the corresponding average noise levels at full speed (noisiest) operating conditions. The table also shows the fraction of its operating time during which a machine typically is used in its noisiest mode, and the fraction during which it is used in its next noisiest mode (called "reduced speed" in the table and assumed to be 5 dBA quieter than the full speed mode). For the remainder of the time, the machine is assumed to

be used in a mode of operation that makes no contribution to the noise exposure of the workers. This time fraction information and the estimated total number of hours a machine is in use per shift, together with the aforementioned noise levels, permit one to estimate noise doses to which the machines subject nearby personnel.[8]

Also shown in table 3 are the numbers of operators and bystanders who usually work with each machine and the estimated number of machines in use. By adding, for a given machine type, the product of the number of operators and the operator noise dose to the product of the number of bystanders and the bystander noise dose, one finds the "exposure-weighted number of workers" for that machine. If one multiplies this number by the number of machines in use, one obtains the "exposure-weighted population of workers" associated with that machine. The latter is a convenient measure of the noise exposure impact related to the given type of machine.

One may conclude from table 3 that ore trucks and load-haul-dump machines have the predominant impact on personnel exposure, with personnel carriers, front-end loaders, service trucks, tractors, locomotives, shuttle cars, and air compressors (in that order) contributing to a lesser extent.

The estimates shown in table 3 do not account for a worker's being exposed to noise from more than one machine at a time. Although two or more machines often are used in conjunction with each other, their operations usually are cyclic, so that only one is operating at its noisiest part of the cycle at any instant. Also, the nearest machine usually dominates a worker's exposure, so that neglecting the effects of the nearby machines results in errors in the exposure estimates that are smaller than those inherent in the data on which these estimates are based; thus, no significant error results from neglecting the effects of simultaneous exposure to more than one machine.

NOISE CONTROL

General Principles

Importance of Attenuating Dominant Contributions

In general, the noise from any one source reaches a person's ears via several paths, both direct airborne paths and reflections from various surfaces; in addition, sound may propagate along or through structures (in the form of vibrations). Just as repair of small holes in a leaking roof is useless unless the large holes are closed off, reducing the noise of lesser sources and paths has practically no effect on a person's exposure unless the contributions from the dominant sources and paths are reduced.

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[8] An alternate method of obtaining noise dose data directly is to use a statistically significant sample of noise dosimeter data.

TABLE 3. - Typical worker-machine scenarios for noise impact over an 8-hour shift

Mining equipment by model	Total number in service (extrapolated from field survey)	Typical horsepower, hp	Full power or maximum speed operation		Duty cycle,[1] T	Typical daily shift use, hours	Number of workers		Fractional exposure[2]		Relative impact (sum of people x-exposure, x-machines)
			Typical operator sound level, dBA	Below-ground bystander sound level, dBA			Operator	Others	Operator	Others	
Load-haul-dumps....	690	150	101		0.8	6	1		3.0		2,070
Front-end loaders..	300	150	100		.8	4	1		1.7		510
Skid-steer loaders.	60	50	98		.8	4	1		1.3		78
Ram haulers........	40	150	98		.8	6	1		2.0		80
Ore trucks.........	820	150	100		.8	6	1		2.6		2,132
Roof bolters and scalers...........	70	50	96	96	.5	[3]2	1	2	.4	0.4	84
Jumbo drills.......	210	50	96	95	.5	[3]1	1	2	.2	.2	126
Shuttle cars.......	90	50	96	95	.5 + 0.3(@ -5 dB)	6	1	1	1.3	1.1	207
Locomotives........	150	50	96	95	.5 + 0.3(@ -5 dB)	4	1	1	.9	.8	255
Explosive buggies..	70	100	96	96	.5 + 0.3(@ -5 dB)	4	1	1	.9	.9	126
Tractor-trailer units.............	30	200	98		.8	6	1		2.0		60
Personnel carriers.	380	50	96	94	.5 + 0.3(@ -5 dB)	1	1	6	.2	.2	532
Service trucks.....	380	50	96	94	.5 + 0.3(@ -5 dB)	2	1	2	.4	.3	380
Tractors...........	160	50	98	95	.5 + 0.3(@ -5 dB)	4	1	1	1.1	.8	304
Bulldozers.........	30	75	100		.8	4	1		1.7		51
Motor graders......	60	100	98		.8	4	1		1.3		73
Welders and generators........	20	10	85	80	1.0	4	1	2	0	0	0
Shotcrete machines.	20	50	96	94	.5 + 0.3(@ -5 dB)	6	1	1	1.3	1.0	46
Transit mixers and placers...........	60	50	96	94	.8	6	1	1	1.5	1.1	156
Pumps..............	10	50	96	92	1.0	8		2		1.3	26
Air compressors....	30	150	100	98	1.0	8		2		3.1	186
Jeeps..............	250	50	96	92	.5 + 0.3(@ -5 dB)	1	1	1	.2	.1	75
Cranes and shovels.	40	150	100	98	.5	2	1	1	.7	.5	48
Pickup trucks......	30	100	96	93	.5 + 0.3(@ -5 dB)	1	1	1	.2	.1	9

[1]The difference between the indicated fraction and 1.0 corresponds to time during which the sound level is 10 dB below SPL at maximum speed or full power.
[2]90 dBA for 8 hours corresponds to 1.0.
[3]Time indicated is for transport mode of operation only.

Major Sources and Paths

In diesel-powered mining equipment, the engine generally constitutes a major source of noise. Engine noise may come from the exhaust, the intake, and the casing (that is, the block and accessories attached to it); also, the cooling fan may be a significant noise source. The transmission, drive train, and hydraulic system also tend to be significant noise sources.

Noise radiated from the various sources may reach the operator by propagation through the air, either directly or via reflections. In addition, vibrations produced by the engine and other mechanical components tend to travel through heavy structures, such as frame rails, to lighter structures that then radiate sound somewhat in the manner of a loudspeaker.

The relative importance of the various noise sources and paths differs for different machine types and models.

Reduction of Noise of Diesel-Powered Equipment

In general, the noise exposure of a miner associated with a given machine may be reduced by obstructing the sound propagation between the important noise sources and the worker. Practical and economical considerations generally do not permit one to modify the primary noise sources or to replace them with quieter ones (except relatively early in the development cycle of new machines). Consequently, practical reduction of the noise of machines in use at mines generally has obstruction of the propagation paths as its first concern.

As mentioned previously, sound for a given source may reach a miner by propagation through the air, including reflections, and also by propagation along and through structures. Thus, one must deal with blocking the airborne paths and also the structural paths.

Airborne Paths

Full enclosures generally are the most efficient for obstructing the radiation of sound from such sources as engines or transmissions. The effectiveness of such an enclosure increases with the mass of its walls, and it is greater if some acoustically absorptive material is also placed within the enclosure.

Where cooling or access requirements do not permit the use of complete enclosures, *partial enclosures* or *barriers* may be used. These tend to be considerably less effective than full enclosures, because they do not interfere with sound that is propagating in directions away from them or past their ends and that may then be reflected in the direction of concern. The effectiveness of a partial enclosure or barrier may be enhanced by placing acoustically absorptive material on the sides that face the noise sources. Because the noise reduction one obtains with a partial enclosure or barrier usually is not limited by the sound that passes through it, but by the sound that gets around it, increasing the barrier or enclosure mass (which reduces the sound passing through these structures) usually results in little additional noise reduction.

Mufflers are devices that obstruct the propagation of sound out of pipes or ducts, largely by reflecting some of the sound back toward the sources in such a way that the reflected pressure waves cancel the outgoing waves to a considerable extent. Engine exhaust mufflers must be matched to the engine so as to be effective accoustically, yet not produce excessive backpressure.

Like mufflers, *silencers* obstruct the propagation of sound out of pipes or ducts (for example, out of air intakes). However, silencers work not by reflecting sound internally, but by absorbing sound. Thus, silencers generally consist of acoustically lined pipes or ducts with baffles or louvers of acoustically absorptive material inside them. Silencers generally must be selected to provide the desired sound attenuation without excessive obstruction of air flow.

Structureborne Paths

The propagation of vibrations along structures (vibrations that may cause structural surfaces to radiate sound in loudspeakerlike fashion) usually may be obstructed efficiently by inserting *vibration-isolation elements* into the propagation path. Such elements typically need to be much softer than the structure they join; they may consist of rubber mounts placed between a vibrating engine or transmission and its supports or of flexible hose inserted in a run of rigid hydraulic tubing.

The remainder of this Information Circular discusses how these basic principles were applied to the noise control of two machines identified in the survey to be major contributors to the noise overexposure problem in underground metal and nonmetal mines.

MACHINES QUIETED

Diesel-powered machinery used in mines can be divided into two broad categories: loading/hauling equipment and service vehicles. Machines in both categories are noisy and numerous. The 1975 census showed that 2,200 loaders-haulers were being used in U.S. mines, and that 690 were load-haul-dump vehicles. Service vehicles--a term that covers all vehicles used to move personnel and equipment (lube trucks, maintenance vehicles, explosive trucks, drill carriers, and any vehicle that carries personnel are included)--ran a close second: 1,800 were in mines in 1975. The Bureau of Mines selected one machine from each of these categories for a demonstration of noise control feasibility. One was a load-haul-dump (LHD) machine, the other a personnel vehicle.

Sound levels of both machines categories are high. Typical sound levels on LHD machines, measured at the operator's ear, reach 100 dBA. The average sound level of service vehicles is 96 dBA.

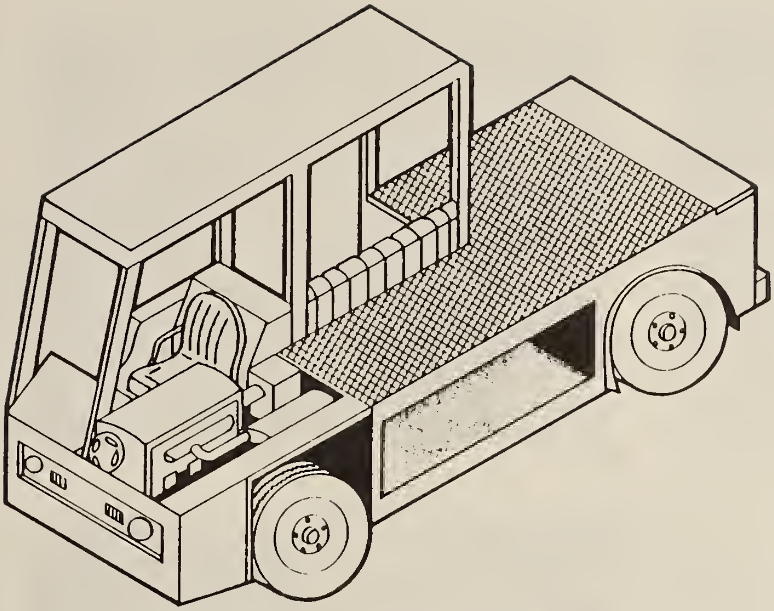


FIGURE 1. - Getman dispatch vehicle.

Personnel Vehicle

A three-passenger Getman[9] dispatch vehicle (fig. 1) was used in the noise control demonstration. This vehicle has two models, the other carrying 12 passengers. Both models are the same size; the extra space on the three-passenger vehicle is used for material handling or as a portable maintenance-service facility.

The vehicles are 18 ft long, with a wheelbase somewhat over 9 ft. Power is supplied by a 45-hp, four-cylinder Deutz air-cooled diesel engine (Model F4L-912W) through a four-speed manual transmission. Body metal is primarily 1/4-inch steel plate. The engine is located immediately to the operator's left, and, in the unquieted vehicles, the engine is fully exposed.

Because of the exposed engine and the operator's closeness to it, the sound level at the operator's ear is considerably higher than in most service vehicles of similar horsepower. The measured sound level was 101 dBA at high idle, compared with an average 96 dBA for similar machines given in table 3.

Source Levels

Four different sources of noise contribute to the 101-dBA sound level at high idle of Getman dispatches:

- Engine.
- Intake.
- Cooling fan.
- Exhaust.

Measurements and diagnoses of these sources of noise indicating their levels are shown in table 4. The engine, then was by far the largest contributor to the total noise of the dispatch vehicle, with the intake and

[9] Reference to specific makes or models of equipment is made for identification only and does not imply endorsement by the Bureau of Mines.

cooling fan about equal in contribution and the exhaust relatively unimportant.[10] A noise control package was designed that included:

Engine:

- A barrier or partial enclosure around the engine.
- An acoustically absorbent lining for the interior of the engine compartment.
- Sealing for all holes and cracks in the engine enclosure.

Intake:

- Installation of a silencer in the intake line.

Muffler:

- Asbestos wrapping for the muffler shell.

TABLE 4. - Source levels on the Getman dispatch vehicle

Source	Level, dBA	Test condition
Engine.........	100	High idle.
Intake.........	89	
Fan............	90	
Exhaust........	<80	

The fan received no specific noise control, because the enclosures would reduce fan, as well as engine noise.

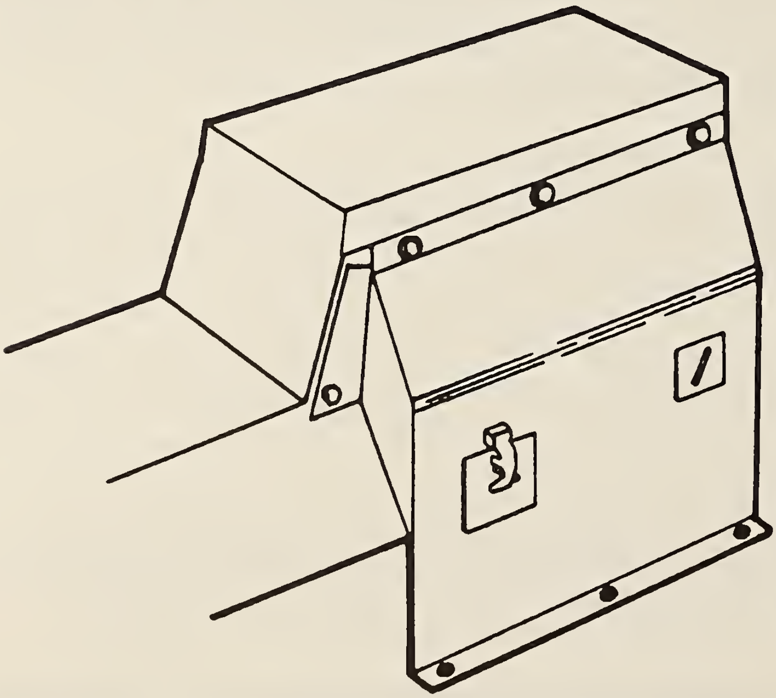


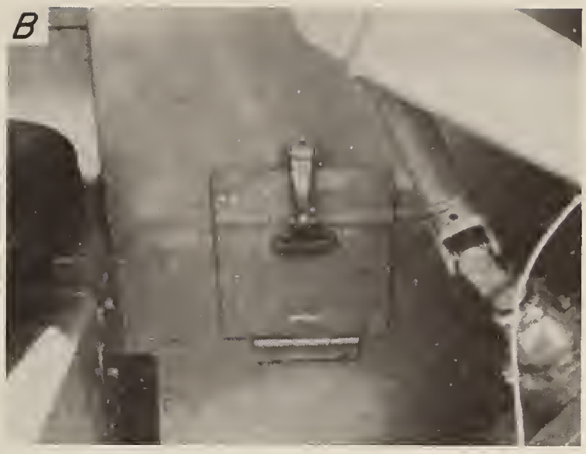
FIGURE 2. - Sketch of removable partial engine enclosure.

Engine Enclosure

The engine partial enclosure is shown in figures 2 and 3. It is constructed of 1/8-inch-thick sheet metal.

The larger door (approximately 6-inch-square) provides access to the oil dipstick (fig. 3B), and the smaller door provides access to the oil filler cap (fig. 3C). Gasket stripping was used on the edges of all panels, doors, and cover plates to ensure a tight seal.

[10] The contribution of the exhaust is low because the dispatch comes equipped with an exhaust muffler.



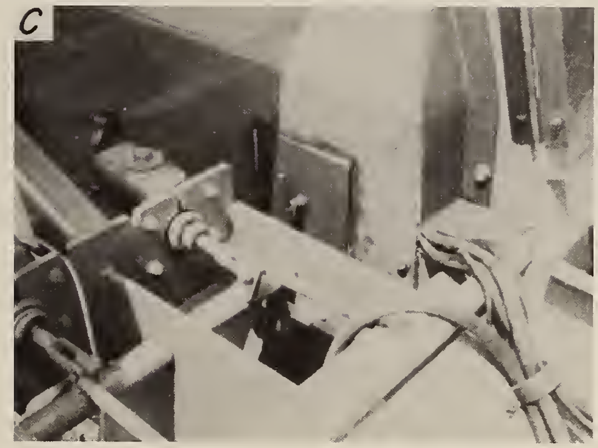


FIGURE 3. - Removable panel for partial enclosure. *A*, Enclosure; *B*, oil dipstick access; *C*, oil filler access.

Although the prototype enclosure was bolted to the Getman dispatch, similar enclosures could be attached by quick-release fasteners to cut down maintenance time.

Acoustically Absorptive Lining

The engine compartment of the Getman dispatch was lined with acoustically absorptive materials--fiberglass and polyurethane foam[11] in equal parts--to prevent the sound level from building up because of repeated reflections of noise within the engine space.

In addition, plastic foam was applied to the underside of the canopy, over the operator's head. These treatments are illustrated in figure 4. The film-wrapped fiberglass was held to the surface of the machine by the expanded grating, which in turn was bolted to the machine.

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[11] Although the polyurethane foam does meet the acoustic requirements, it has an exceptionally high flame spread index and emits toxic fumes when burned. It is therefore recommended that future treatments use more suitable materials, such as fiberglass.

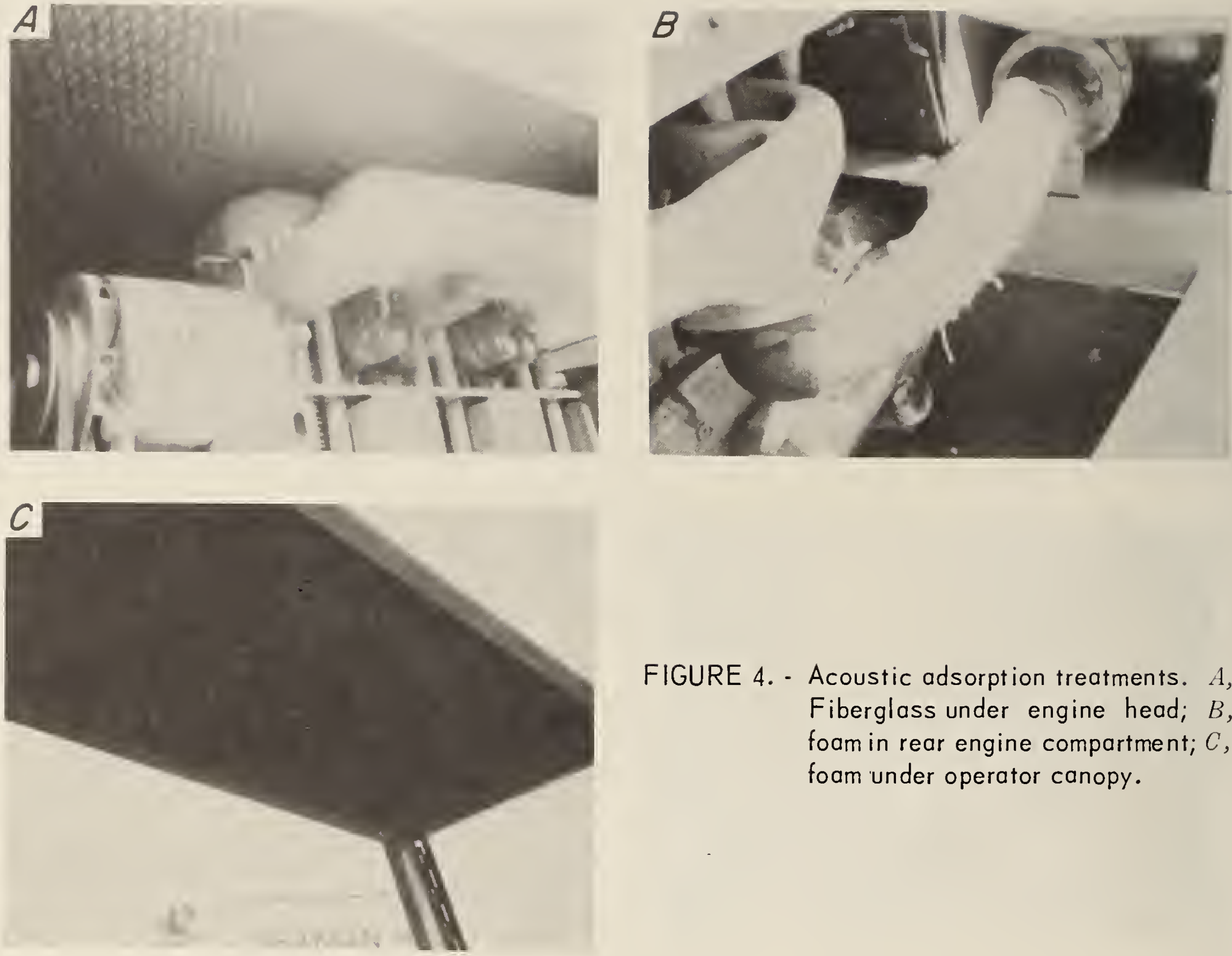

FIGURE 4. - Acoustic adsorption treatments. *A*, Fiberglass under engine head; *B*, foam in rear engine compartment; *C*, foam under operator canopy.

Hole and Crack Sealing

Great care was taken to seal all holes and cracks in the structure around the operator to make sure no engine noise would leak through. Figure 5 illustrates this meticulous sealing, including:

- A rubber boot around the shift lever.
- A steel cover plate bolted over a hole in the panel to the operator's immediate left.
- A cover plate over a hole on the rear of the transmission and battery compartment.

In general, any opening one-fourth inch or larger was considered a "hole", and was sealed with a steel plate to which gasket stripping had been applied.

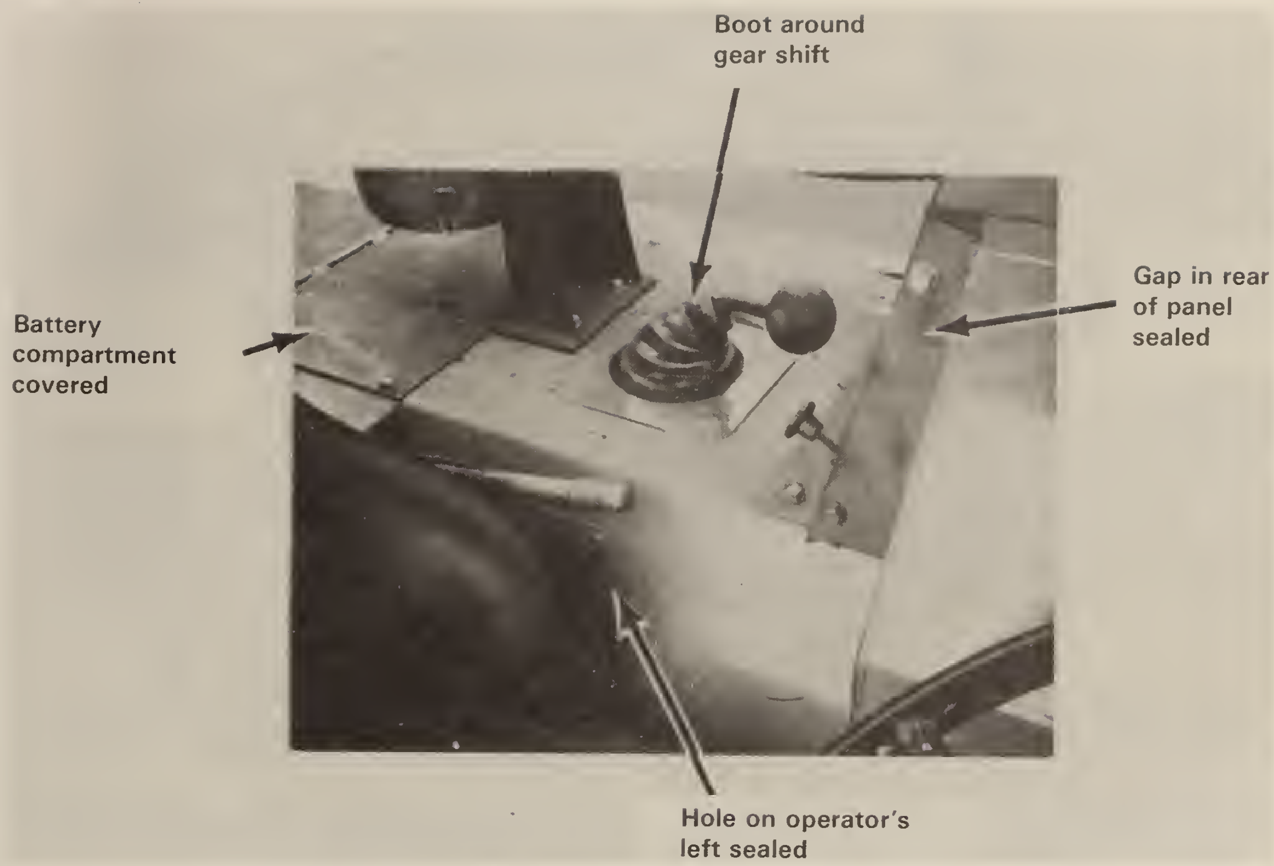

FIGURE 5. - Examples of sealed holes and voids, operator vicinity.

Intake, Fan, and Exhaust Noise

To cut air intake noise, a standard cylindrical silencer was installed between the air cleaner and the engine. This installation involved moving the filter a few feet toward the rear of the vehicle and bolting the air cleaner to the frame. The muffler was wrapped with asbestos.

Since air recirculation within the enclosure could cause overheating, a metal panel and cowling were installed on the front of the engine hood. As figure 6 shows, cooling air entered the fan opening front, passed by the cylinder fins, and exited to the left of the engine. Components of the fan inlet are shown in figure 7.

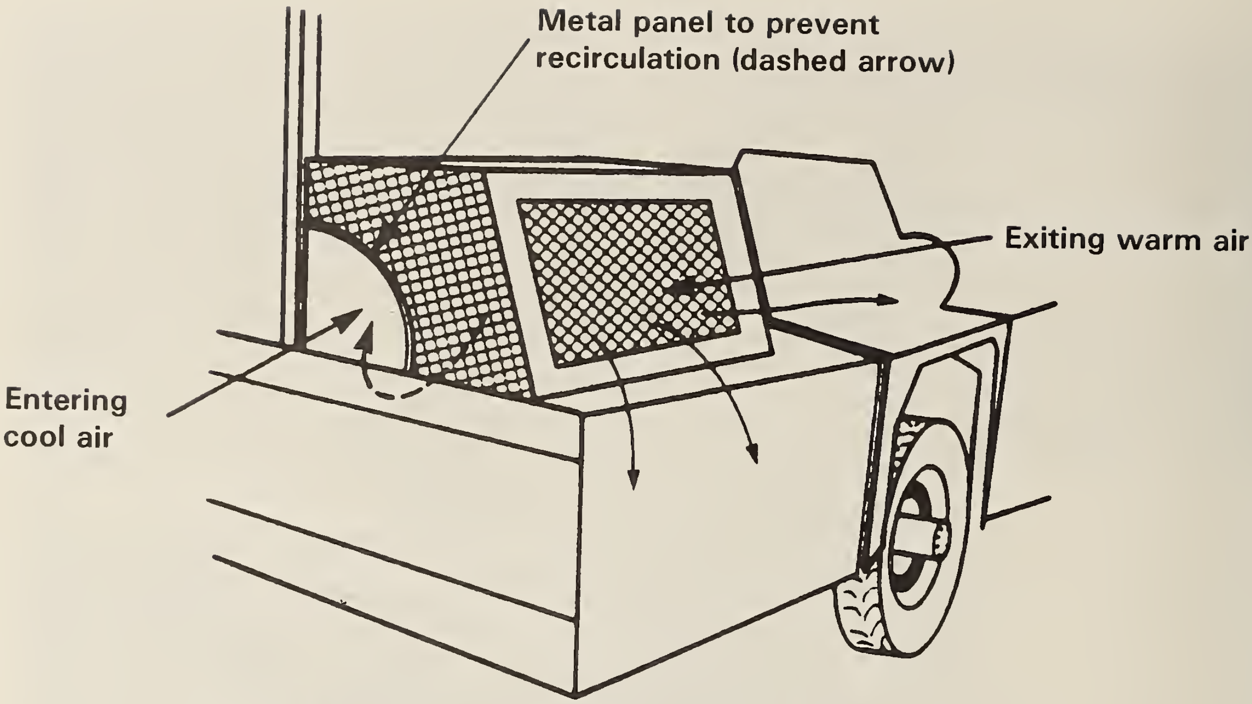

FIGURE 6. - Fan inlet modifications to prevent recirculation.

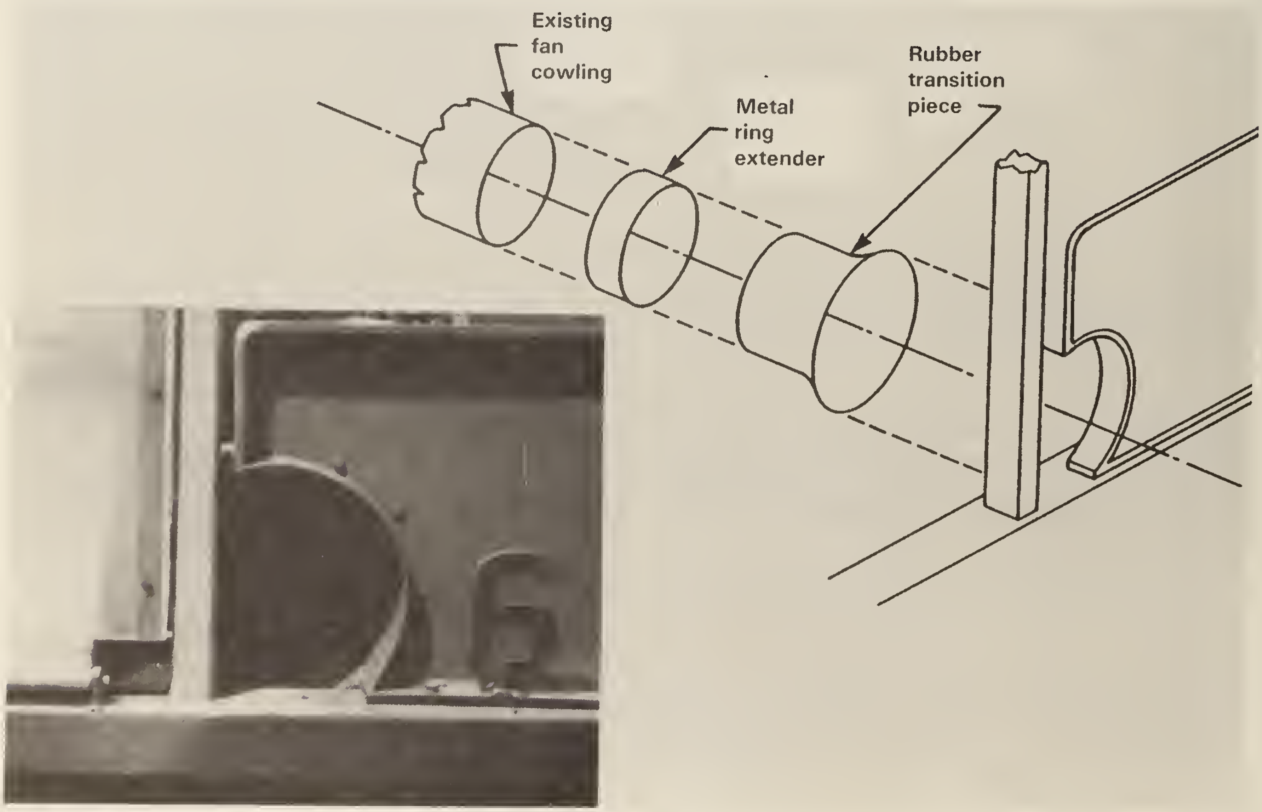

FIGURE 7. - Fan inlet configuration.

Results

When it was completely installed, the noise control package--engine enclosure, acoustically absorbent lining in the engine compartment, sealing, intake silencer, and asbestos wrapping of the muffler--cut the noise of the Getman dispatch by 14 dBA. Without the quieting package, the overall sound level of the dispatch was measured as 101 dBA; after quieting, it was measured as 87 dBA. Figure 8 shows spectra recorded before and after the treatment. Measurements in both cases were taken to the right of the operator's right ear, with the engine at high idle.

Service Experience

Four months after the Getman dispatch had been put in service at International Salt's Detroit Mine, the vehicle had been used for 60 to 70 hours and had received typical periodic maintenance (engine oil change, filter changes, tuneup, etc.). There had been no noticeable change in the acoustics of the dispatch; it was as quiet as when the noise reduction package was first applied.

Mine workers said they preferred to drive the demonstration vehicle "because it was quieter." They suggested that quick-release fasteners be applied to the partial enclosure, which must be removed for preventive maintenance every 3 months or whenever repairs are made on the engine.

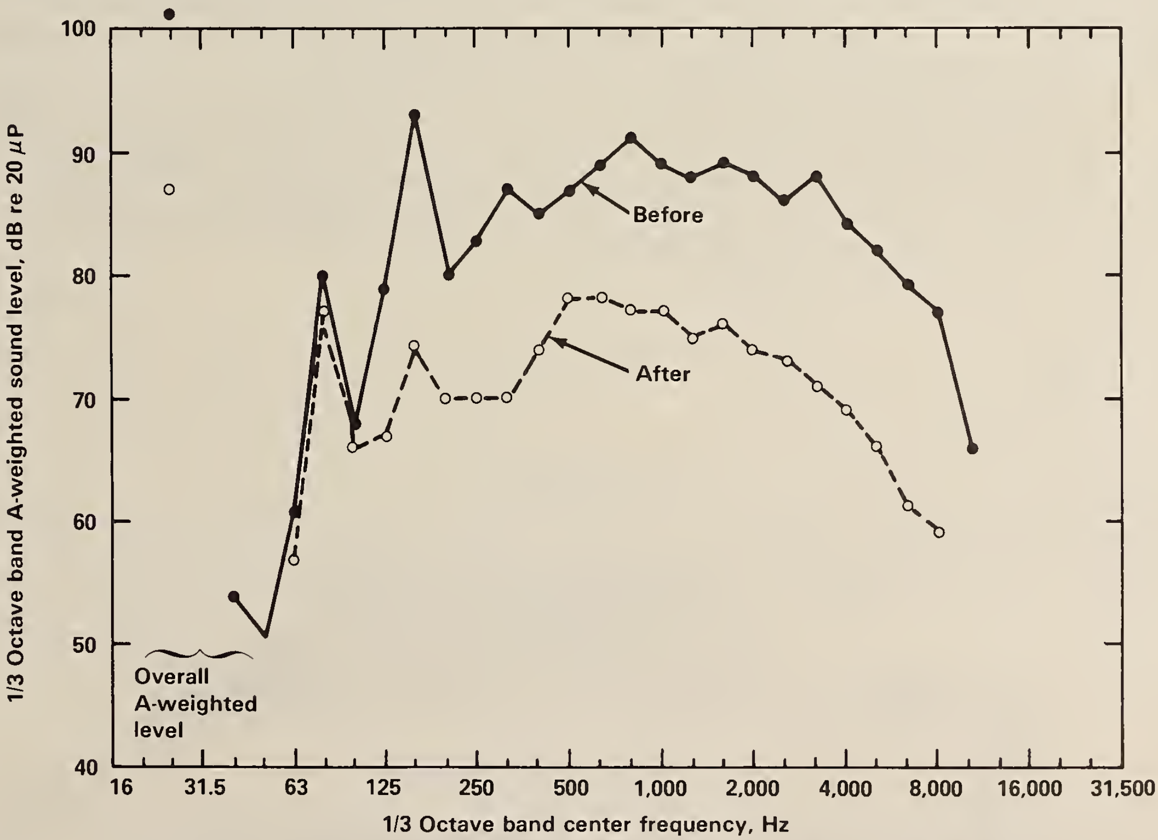

FIGURE 8. - Getman dispatch operator sound level—before and after quieting.

FIGURE 9. - Load-haul-dump machine.

Load-Haul-Dump Machine

The Wagner ST-5A Scooptram® (fig. 9) is one of the most widely used load-haul-dump (LHD) machines in underground mining. It is a low-profile loader, 67 inches high, with a 5-cu-yd bucket mounted on the front. Just to the rear of the bucket is the center-articulated steering wheel, which allows short-radius turns in mines. The driver sits at the side of the aft section of the vehicle, facing inward, since the vehicle has the same tram capabilities in either forward or reverse. Also located on the aft section is the air-cooled diesel engine, the torque converter, and the transmission.

The diesel engine of the ST-5A is a Deutz 8-cylinder Model F8L-714, rated by the Bureau of Mines at 180 hp at 2,300 rpm. A single-stage Clark Model C-8402 torque converter is connected directly to the engine. A shaft from the torque converter drives the 4-speed Clark Model 3421 transmission, which in turn drives the front and rear differentials.

Major sources of noise were--

- Drive train.
- Engine.
- Cooling fan.
- Intake and exhaust.

Measurements of these sources of noise indicating their levels (at the operator's ear) are shown in table 5.

TABLE 5. - Source levels on the Wagner load-haul-dump machine

Source	Level, dBA	Test condition
Drive train.....	101	Rated speed in 4th gear.
Engine..........	97	High idle.
Cooling fan.....	94	High idle.
Intake..........	90	High idle.
Exhaust.........	93	Torque converter stall.

Noise Reduction Package

Two noise sources--the intake and the exhaust--were eliminated from further consideration. The air intake was eliminated because its noise level was already low; the exhaust was eliminated because its principal contribution was in the low-frequency range and because noise reduction would have required designing a completely new muffler.

The drive train, engine, and fan were left as noise sources to be quieted. The package from them included:

Drive train:

- Sealing holes in operator compartment.
- Transmission compartment cover.
- Cover on water and fuel tank.
- Acoustically absorbent lining in water and fuel tank compartment.
- Acoustically absorbent lining in torque converter compartment.
- Cover over torque converter.
- Vibration isolation of transmission.

Engine:

- Enclosure.
- Stiffening of frame rail.

Cooling fan:

- Baffle on grill.
- Sealing of fan area.

Drive Train

The principal hole that needed sealing was around the steering column. It was sealed with a shroud with an elongated hole through which the steering column can pass and can also move to the three positions. The shroud was bolted through a gasket to the existing structure.

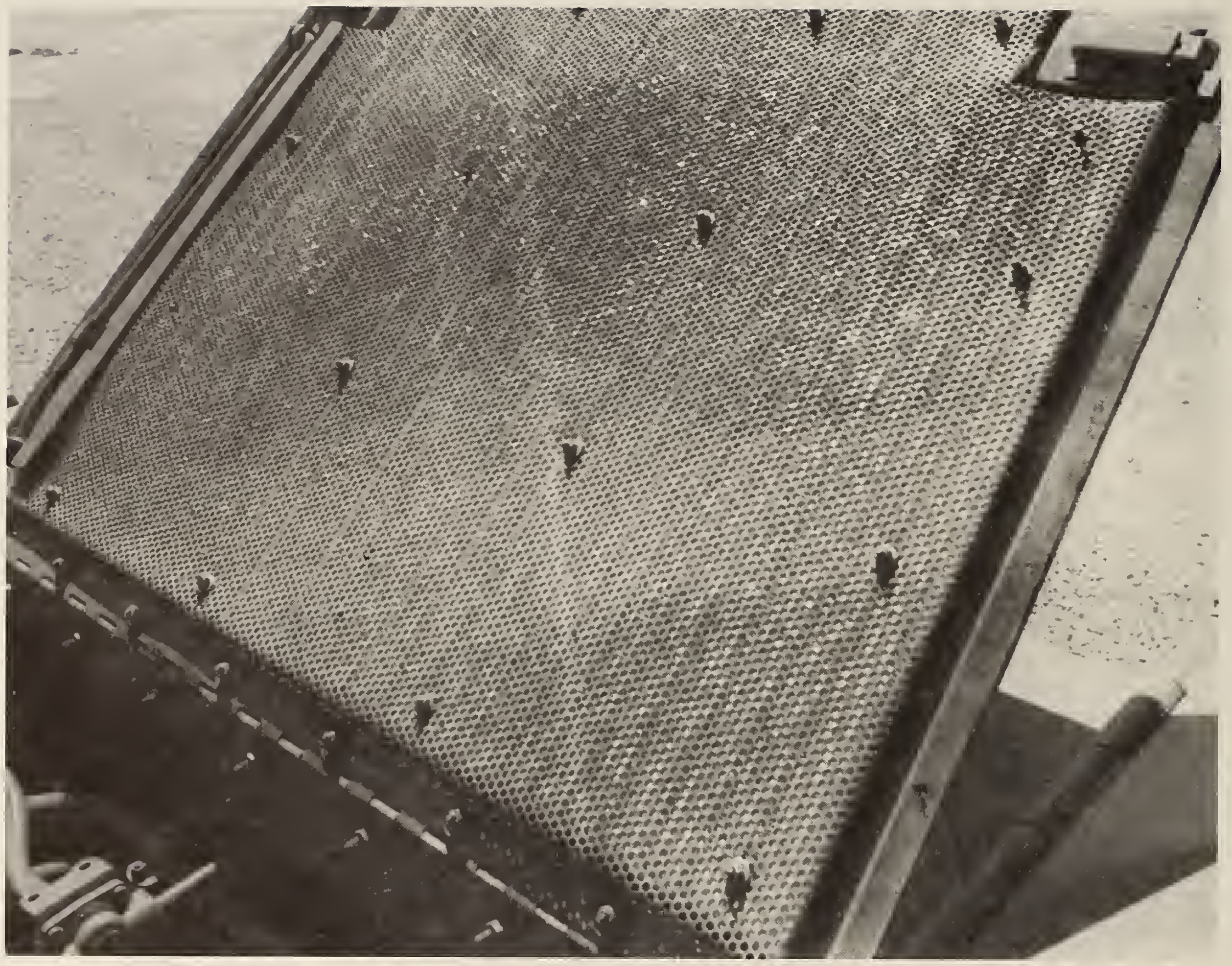

FIGURE 10. - Transmission compartment cover.

Covers (fig. 10) were installed around the transmission compartment. The interior surface was lined with 1-inch-thick 2-lb/cu-ft polyurethane foam with 0.0005-inch-thick aluminized Mylar facing. The facing was covered with a 22-gage (0.031-inch) perforated steel sheet with 51% open area. These layers were held together with studs welded to the cover plate and capped with washers and nuts.

The transmission hood was vibration-isolated from the main structure of the LHD at the hinge by a rubber washer, as shown in figure 11. In addition, a rubber strip, 1/4 inch thick and 1 inch wide, was glued to the other three sides of the cover.

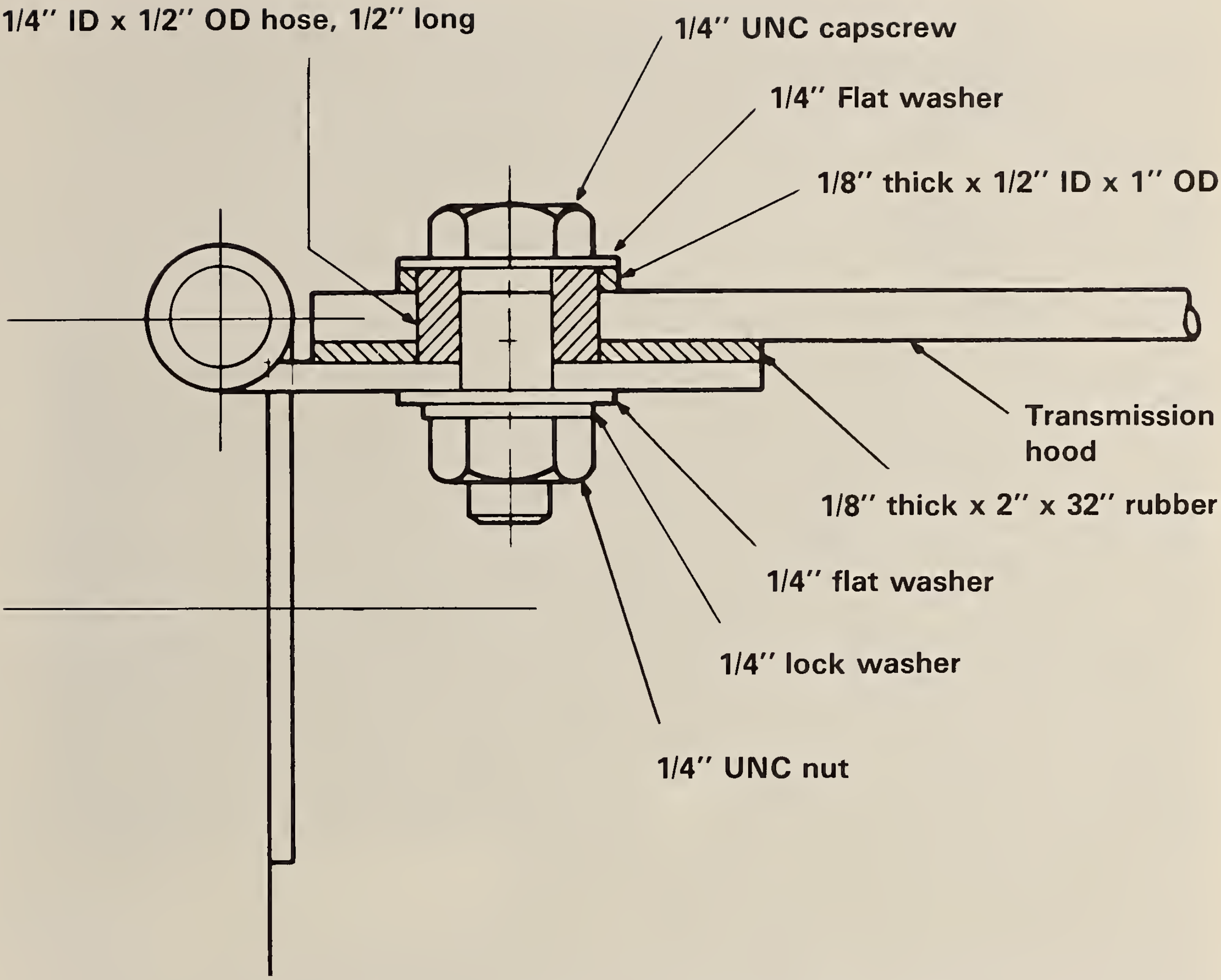

FIGURE 11. - Transmission hood vibration isolation.

The bottom of the transmission compartment was sealed with a belly pan made of 10-gage (0.139-inch) steel. A drain hole allowed transmission fluid to be emptied.

Figure 12 shows the cover plate used to seal holes in the transmission compartment in the center, where the machine is pivoted. The cover was made of 10-gage steel and has 1/2 inch of polyurethane foam with 1/8-inch leaded rubber bounded to it.

Another hole through which transmission noise leaked was the grate at the operator's feet. This was sealed by welding a plate underneath the grate.

The water and fuel tank cover, noisy because of vibration, was quieted by adding a second cover. The second cover was vibration-isolated as shown in figure 13; it was made of 10-gage steel, with 1/2 inch of polyurethane

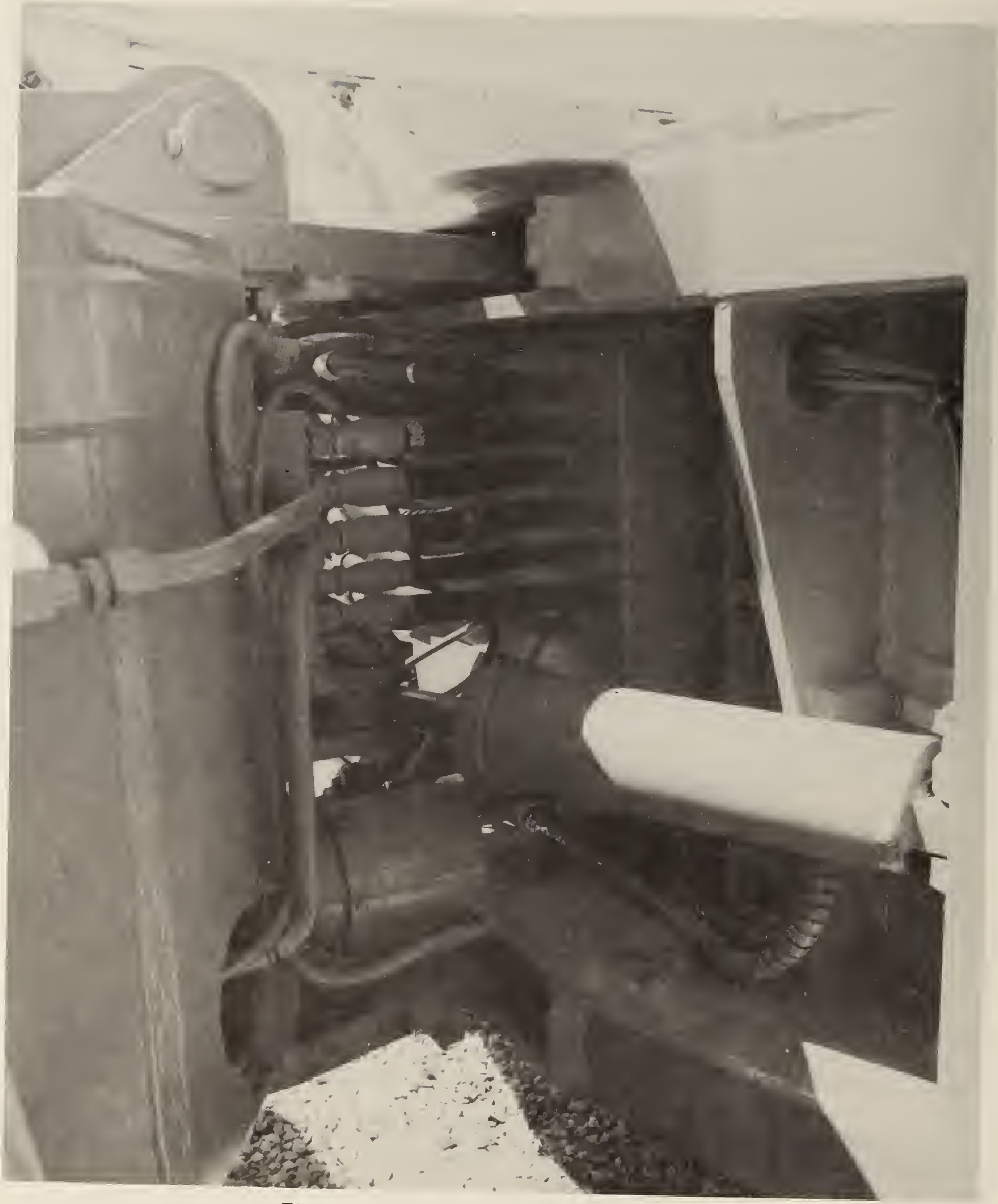

FIGURE 12. - Transmission front cover.

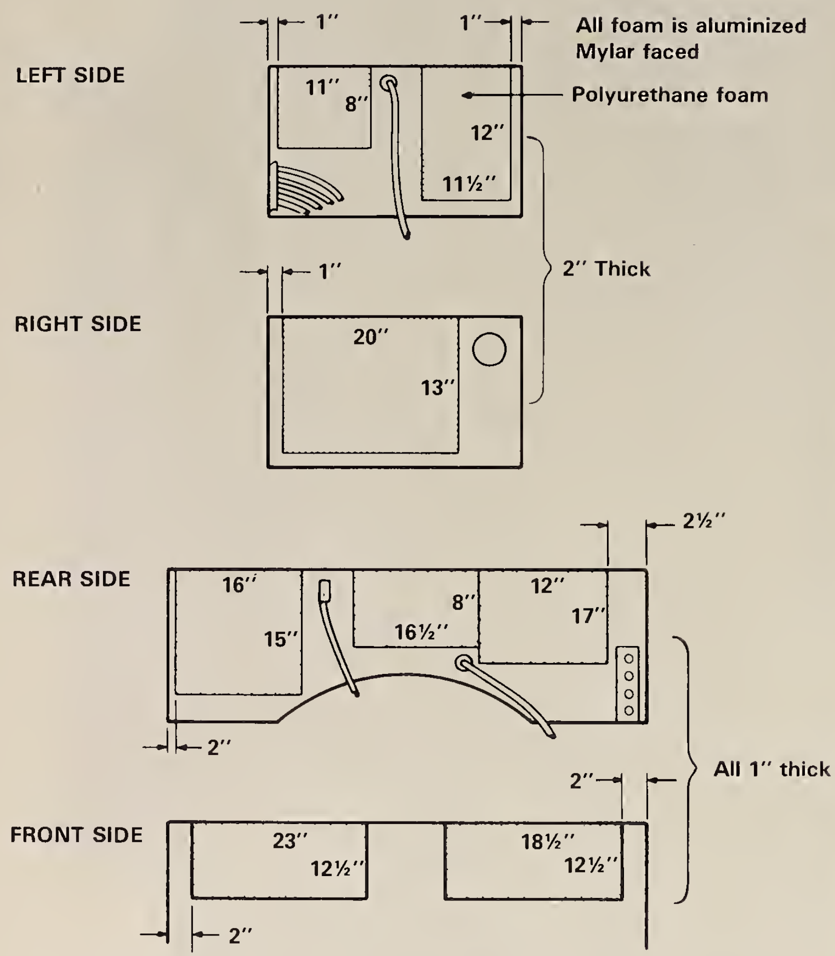

FIGURE 13. - Acoustical treatment for interior of fuel and water tank compartment.

FIGURE 14. - Torque converter cover.

foam and 1/8-inch leaded rubber bonded to it for acoustical absorption and mass addition.

The interior of the water and fuel tank compartment was treated with acoustical absorption material, as shown in figure 13. Approximately 14 sq ft of the 1-inch-thick Mylar-faced polyurethane foam was stud-welded to the front, back, and side surfaces.

The torque converter was quieted with a 10-gage steel cover (fig. 14), to which 1-inch-thick Mylar-faced polyurethane foam was stud-welded. Large buttons covered the studs and held the acoustical material in place.

The interior of the torque converter compartment was lined with acoustical absorption material (fig. 15). Approximately 22 sq ft of the Mylar-faced polyurethane foam was stud-welded to the front, back, side, and top surfaces.

Structureborne noise from the transmission was controlled by installing two Huntington M700 vibration mounts (nominal load capacity: 900 lb) on the transmission (weight: 1,100 lb), at the points where the transmission was hard-mounted to the main structure of the machine. The transmission vibration-isolation mounting structure is shown in figure 16.

Engine

The diesel engine was quieted with an enclosure (fig. 17) that consisted of a hood, side panels, and belly pan with ducts for cooling air exhaust. Figure 18 shows the parts of the enclosure. When the air-cooled engine was

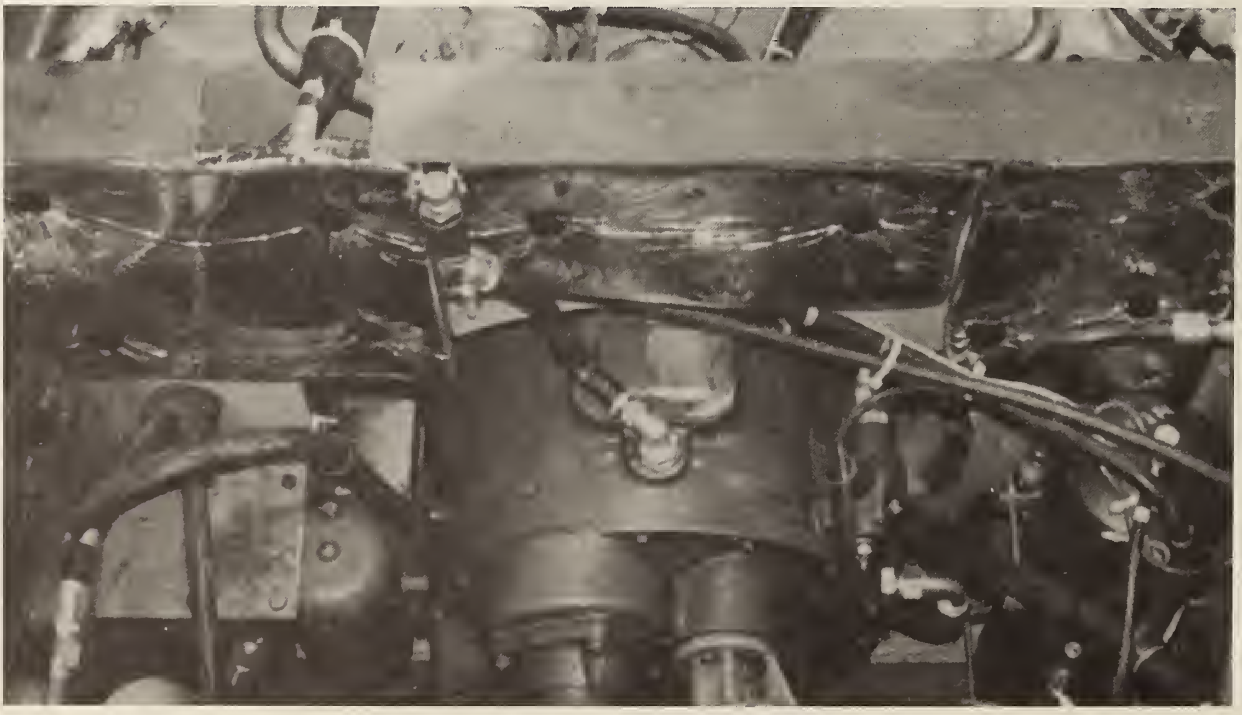

FIGURE 15. - Absorptive materials applied to the interior of the torque converter compartment.

FIGURE 16. - Transmission vibration isolation mounting structure.

FIGURE 17. - Engine enclosure, external view.

FIGURE 18. - Components of engine enclosure. *A,* Hood; *B,* left side enclosure; *C,* right side enclosure; *D,* belly pan and cooling air exhaust ducts.

enclosed, there is a potential for overheating. Cooling capacity was evaluated during two sets of experiments. A prototype enclosure with a lined exhaust duct was designed and built, then tested by noise control engineers and also by Deutz, the manufacturers of the engine. Both groups approved the enclosure design as having sufficient cooling capacity for the engine.

The hood of the engine enclosure (fig. 18A) was made of 10-gage steel hinged to the main structure, with rubber gasketing material applied to the edges to vibration isolate it from the frame of the LHD. It was lined with 1-inch-thick polyurethane foam with 0.0005-inch aluminized Mylar facing protected by perforated steel.

The left- and right-hand enclosures (figs. 18B and 18C) are also 10-gage steel with 2-inch-thick polyurethane foam with Mylar facing held on with studs and buttons.

So that miners could reach the engine, the side enclosures were designed with removable sections attached to the fixed sections with hexhead bolts.

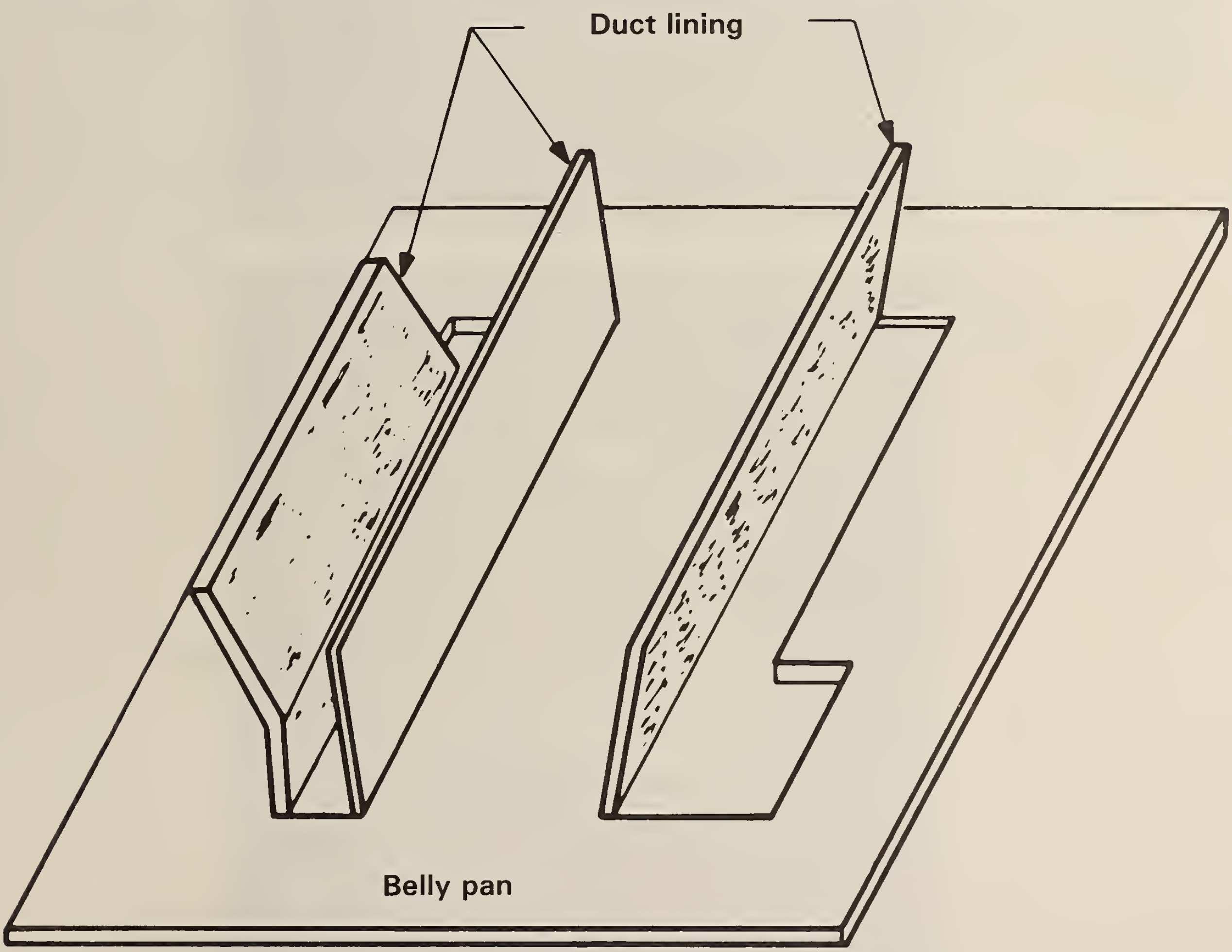

FIGURE 19. - Belly pan with cooling fan exhaust duct lining.

The belly pan and its cooling air exhaust ducts are shown in figure 18D. The pan was made of 5/8-inch-thick steel with two cutouts for exhausting the cooling air. The cutouts provided a total exhaust area of 4.7 sq ft. Figure 19 shows the design of the lined ducts inside the engine enclosure. The ducts were made as separate pieces, were bolted to the belly pan, and were lined with 1-inch-thick, 2-lb/cu-ft polyurethane foam with 0.0005-inch aluminized Mylar protected by 22-gage perforated steel sheet.

Structureborne noise from the engine was quieted by stiffening the frame rail. Triangular gussets, 6- by 6- by 1/2-inch, were welded to the ends of the frame rails, as shown in figure 20.

Cooling Fan

Figure 21 shows the treatments used to quiet the cooling fan. They included (1) sealing the entire area around the fan with 1-inch polyurethane foam with 0.0005-inch aluminized Mylar stud-welded to the structure and (2) placing a baffle on the fan grille. The baffle was covered with 1-inch polyurethane foam that was covered, in turn, with 22-gage perforated steel plate.

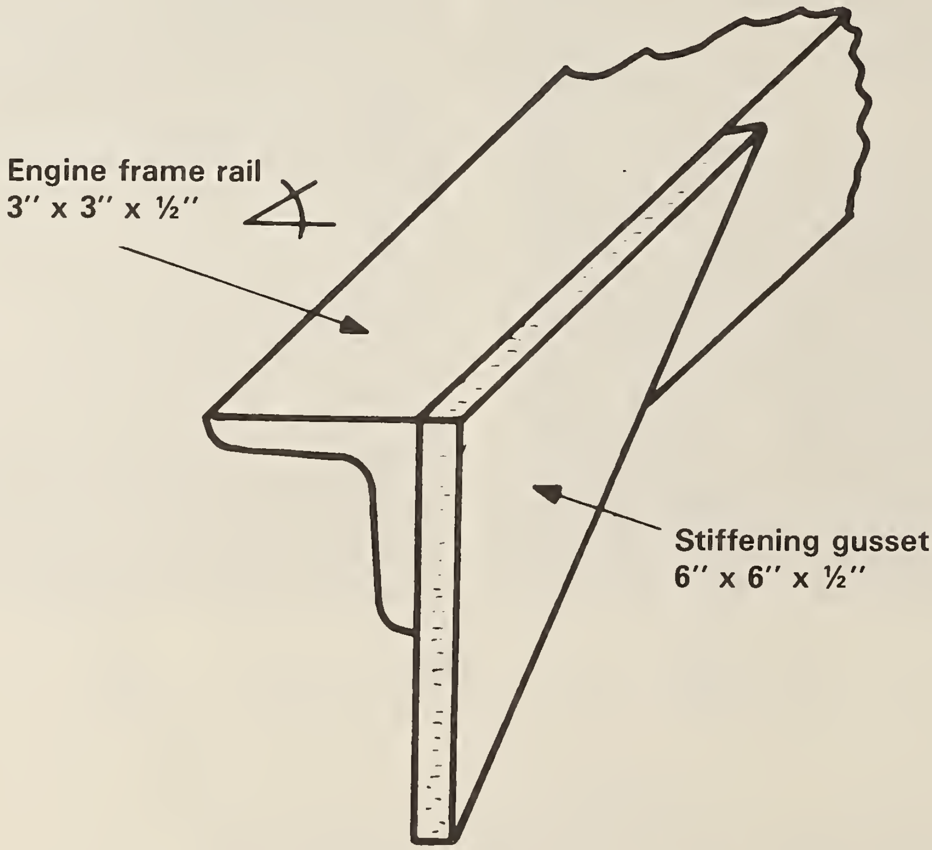

FIGURE 20. - Stiffening applied to engine frame rail.

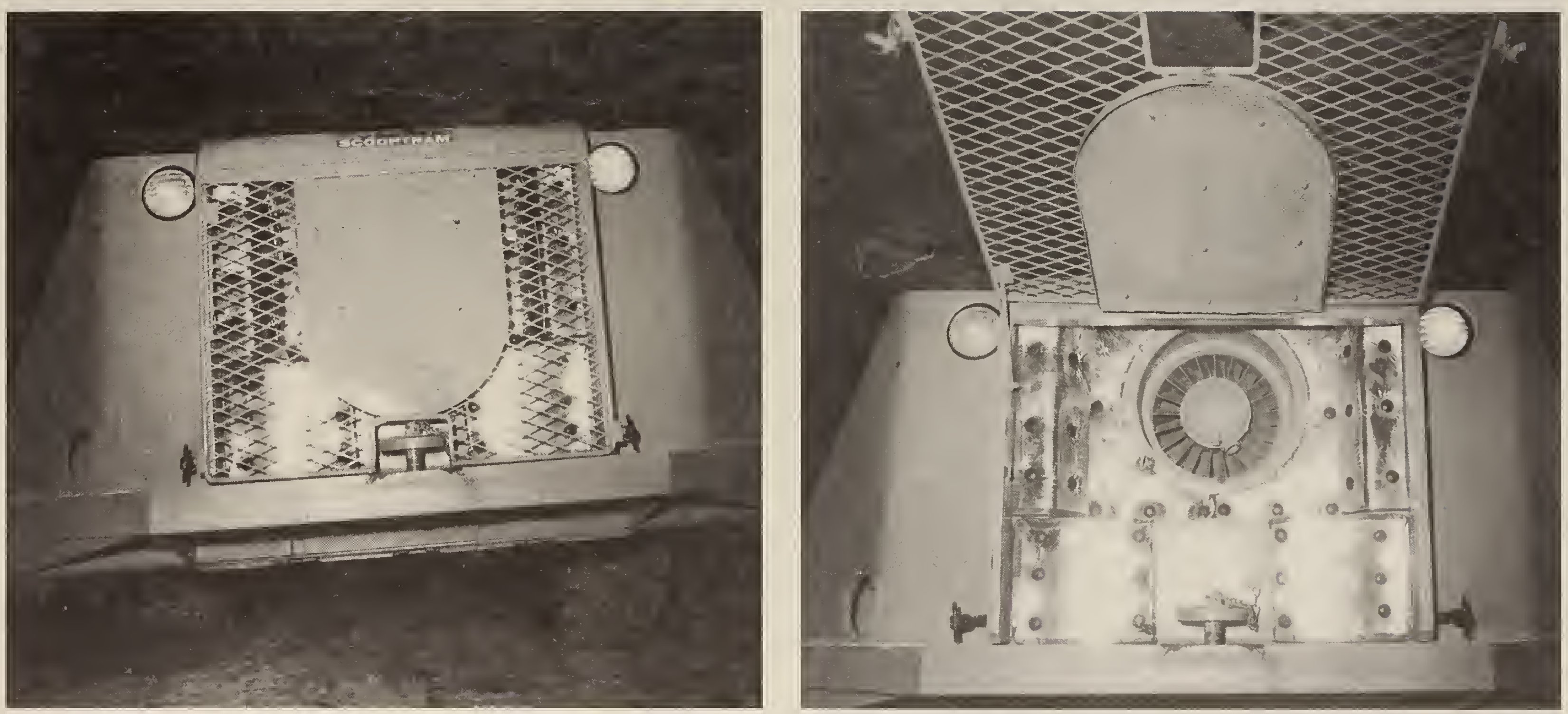

FIGURE 21. - Baffle in lowered (left) and raised (right) positions.

FIGURE 22. - Quieted machine, shown underground at National Gypsum Mine.

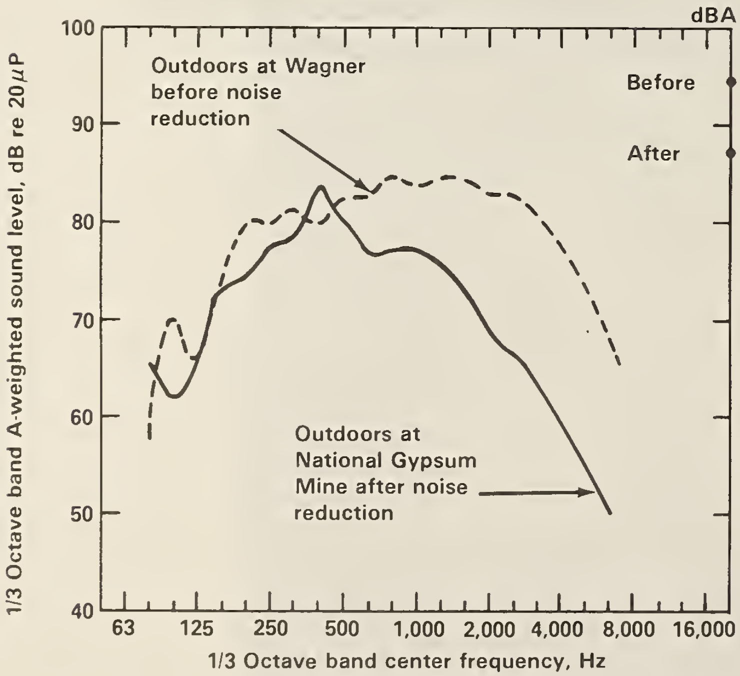

FIGURE 23. - Comparison of above ground and underground sound pressure levels measured on load-haul-dump machines.

Results

The quieted machine is shown (fig. 22) underground at the National Gypsum Mine in Shoals, Ind. A comparison of the spectra measured aboveground before and after noise control is presented in figure 23. In all cases, the measurement was made near the operator's right ear with the engine at high idle. Noise dosimeter measurements made by the Mine Safety and Health Administration (MSHA) indicate that the machine is in compliance when operated underground.

Service Experience

Sixty days after the machine was placed in service, a second, set of noise

measurements was made. There was no noticeable change in the acoustical performance of the machine.

Mine employees reported that the noise control treatments were intact and performing as expected, indicating that the treatments were sufficiently practical for the use they underwent in the mine. A visit to the mine in March 1979 showed that all treatments are still intact after 2-1/2 years of service experience. Acoustical measurements at that time indicated no degradation of the performance of the noise control. (As a result of this program, the manufacturer was encouraged to offer an optional quieting package at the time of purchase.)

CONCLUSIONS

The major contributors to the noise overexposure of underground metal and nonmetal miners by diesel-powered equipment were identified as load-haul-dump machines and ore trucks in the production category and personnel carriers in the support equipment category. The Bureau of Mines selected one piece of equipment from each of these categories for a demonstration of the feasibility of noise control. A load-haul-dump machine was selected to represent the production category; the model chosen, a Wagner ST-5A Scooptram®, was quieted by 7 dBA at the operator's position. The selected personnel carrier, an air-cooled Getman dispatch, was quieted by 14 dBA at the operator's position. Both machines were quieted to a point where they are in compliance with Federal noise regulations for typical operations, and treatments on both machines are sufficiently durable to endure the mining environment.

The techniques used in these demonstration programs are also applicable to the noise control of other diesel-powered underground mining machines. Mine personnel interested in implementing such noise control treatments on these machines or on others are encouraged to obtain copies of the contract reports (see footnote 6).

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